Enhanced CPD DO C

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Sustainability of Different Fluoride Delivery Methods

Abstract: The impact of human-induced global warming is a present issue. The health and social care system is associated with significant use of resources and carbon emissions. The Greener NHS Programme is dedicated to promoting methods that enhance patient care while minimizing the healthcare industry's environmental impact. This article summarizes the evidence for the environmental sustainability of using the fluoride prevention methods that are recommended by the Department of Health.

CPD/Clinical Relevance: The sustainability of the use of fluoride in the prevention of caries is an issue to consider.

Dent Update 2023; 50: 750–756

The impact of human-induced global warming is not a concern for the distant future. It is a present issue that is already underway, causing irreversible consequences for those living today, and will deteriorate further as humans persist in releasing greenhouse gases into the atmosphere. Analysis from the World Meteorological Organization showed that the years 2015–2022 were the warmest 8 years on record.[1] We are already seeing the consequences of climate change. More than 2500 people were killed by heatwaves in the UK in 2020.[2] Sea levels are rising, biodiversity is declining, and polar ice caps are melting, among other global effects.[3]

The health and social care system is associated with significant use of resources and carbon emissions, comprising around 4–5% of the UK's total carbon footprint.[2] It is estimated that NHS dentistry contributes to 3% of the overall carbon footprint of NHS England.[4] In October 2020, the NHS became the world's first health service to commit to reaching carbon net zero emissions.[5] The Greener NHS Programme is dedicated to discovering and promoting methods that enhance patient care while minimizing the healthcare industry's environmental impact (EI). To achieve this objective, the programme encourages practices such as reducing/substituting medicines, reducing energy use, reducing patient travel, and adopting innovative technologies that reduce plastics in healthcare.

Prevention and health promotion is a core principle of developing environmentally sustainable healthcare.[6] In dentistry, preventive approaches to reduce dental caries include diet modification (e.g. sugar reduction) and the use of preventive products such as fluoride, and these can be delivered at the individual or population level. A key element of prevention at both levels is the delivery of fluoride, either via toothpaste, mouth rinse, varnish or water supply. The clinical effectiveness of fluoride in the prevention of dental caries is well established.

In principle the resources required for preventing oral diseases in healthcare have a lower EI than treating those diseases. If a patient has never experienced caries, there will be fewer travel requirements for appointments and a reduced need for resources at the dental clinic. As a result, there will be a net decrease in CO_2 emissions, pollution and resource usage.[7]

However, some methods of prevention will be more resource intensive than others, and therefore, potentially more damaging to the environment. When deciding what prevention regimens to implement on a large scale, environmental sustainability should be considered alongside clinical effectiveness and cost.

The aim of this article is to summarize the evidence for the environmental sustainability of the following fluoride prevention methods, that are recommended by the Department of Health:[8,9]

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Impact category	Description
Climate change	Potential for global warming from greenhouse gas emissions
Freshwater and terrestrial acidification	Acidification of soils and freshwater due to gas release
Freshwater ecotoxicity	Harmful effects of toxic substances in freshwater ecosystems
Freshwater eutrophication	Changes in freshwater organisms and ecosystems caused by excess nutrients
Marine eutrophication	Changes in marine organisms and ecosystems caused by excess nutrients
Terrestrial eutrophication	Changes in land organisms from excess nutrients in soil and air
Carcinogenic effects to human health	Harm to human health that causes or increases cancer risk
Ionizing radiation effects to human health	Potential damage to human DNA from ionizing radiation
Non-cancer toxicity to human health	Harm to human health that is not related to cancer or ionizing radiation
Ozone layer depletion	Air emissions causing stratospheric ozone later destruction
Photochemical ozone creation	Harm to human health from gas emissions that contribute to smog in the lower atmosphere
Respiratory inorganics effects to human health	Harm to human health caused by particulate matter emissions (respiratory disease)
Water scarcity	Potential for water deprivation to humans and ecosystems globally
Fossil resource use	Depletion of natural fossil fuels
Land use	Depletion of natural resources, change in soil quality, and reduction in biodiversity
Minerals and metals resource use	Depletion of non-fossil fuel resources

Table 1. Impact categories.

- Toothpaste;
- Varnish;
- Mouth rinse;
- Water.

Measuring sustainability

Life cycle assessment (LCA) is a systematic and standardized way to quantify the EI of a material or service, such as fluoride prevention. LCAs are arguably more comprehensive than just a carbon footprint alone, as they consider multiple measures of environmental sustainability rather than just climate change.[10] The Product Environmental Footprint (European Union guidelines)[11] recommend measuring 16 'impact categories', which are outlined in Table 1.

Each of these impact categories is measured with different units and methodology, according to EU guidelines.[11] For all categories, the higher the result, the worse the environment impact on the planet. Results can be compared to the average person's annual environmental footprint, which is called normalization.

As LCA data can be tricky to interpret, it is presented in this article in two ways:

Impact category (units)	1450ppm	2800ppm	5000ppm
Climate change (kg CO_2 eq)	0.34101	0.34101	0.34028
Acidification (mol H+ eq)	1.55×10^{-3}	1.55×10^{-3}	1.56×10^{-3}
Freshwater ecotoxicity (CTU)	0.43993	0.43993	0.43964
Freshwater eutrophication (kg P eq)	9.47×10^{-5}	9.47×10^{-5}	9.50×10^{-5}
Marine eutrophication (kg N eq)	5.1×10^{-4}	5.1×10^{-4}	5×10^{-4}
Terrestrial eutrophication (mol N eq)	3.03×10^{-3}	3.03×10^{-3}	3.03×10^{-3}
Carcinogenic effects (ctuh)	8.29×10^{-9}	8.29×10^{-9}	8.29×10^{-9}
Ionizing radiation (kg U235 eq)	7.62×10^{-3}	7.62×10^{-3}	7.75×10^{-3}
Non-carcinogenic effects (ctuh)	2.88×10^{-8}	2.88×10^{-9}	2.91×10^{-8}
Ozone layer depletion (kg CFC-11 eq)	1.16×10^{-8}	1.16×10^{-8}	1.20×10^{-8}
Photochemical ozone creation (kg NMVOC eq)	1.04×10^{-3}	1.04×10^{-3}	1.04×10^{-3}
Respiratory inorganics effects (disease included)	3.26×10^{-8}	3.26×10^{-8}	3.24×10^{-8}
Dissipated water (m^3 water eq)	0.35824	0.38524	0.35704
Fossil use (MJ)	6.68317	6.68317	6.66184
Land use (pts)	2.40524	2.40524	2.41412
Mineral/metal use (kg Sb eq)	5.95×10^{-7}	5.95×10^{-7}	6.35×10^{-7}

Table 2. LCIA data for different strength fluoride toothpaste.

- Raw life cycle impact assessment (LCIA) data, presented as a table, using scientific numbers where appropriate.
- Fluoride sustainability 'at a glance' summary (see Table 7) to highlight the carbon footprint and any other significant environmental burdens. Although environmental sustainability is about more than just climate change, CO_2e figures are often used in government targets.

Fluoride toothpaste

A tube of toothpaste

LCA data for a single 100-ml tube of fluoride toothpaste was compiled as part of a larger LCA study.[12] Toothpaste has a relatively low carbon footprint (0.34 kg of carbon).[13] To put that into context, it has the same carbon footprint of an average flat white coffee.[14]

Table 2 shows the raw LCIA data or prescription strength toothpastes (e.g. 2800ppm and 5000ppm sodium fluoride), there is very little change in the EI.

In all formulations, it was the ingredient sorbitol that contributed more to the environmental footprint than any other aspect of the toothpaste. Sorbitol is a humectant and is the ingredient in toothpaste that produces its gel-like consistency. It is the largest component in toothpaste by weight, accounting for between 50% and 70% of toothpaste composition. Other highest contributing elements related to the EI of toothpaste include transport, plastic tube and mixing machinery.[12]

Given this data**,** there is no environmental consideration required when it comes to choosing a dose of toothpaste. Instead, the decision should be made based on the patient's age and risk factors.

A jar of toothpaste tablets

Toothpaste tablets are a relatively new product that has been introduced as an alternative to traditional toothpaste. They are marketed as a more eco-friendly option due to their recyclable glass containers and aluminium lids, which are believed to reduce plastic packaging. However, it is important to note that the packaging of toothpaste only accounts for 15% of the plastic tube's environmental impact.[12]

Despite this, toothpaste tablets are thought to have a lower environmental impact than traditional toothpaste because they do not contain sorbitol, which is the primary contributor to the environmental impact of toothpaste tubes. Sorbitol is not included in toothpaste tablets because they

Impact category	Supervised toothbrushing	Targeted provision of toothbrushes and toothpaste
Climate change (kg CO_2 eq)	1.95	2.89
Acidification (mol H+ eq)	8.11×10^{-3}	1.36×10^{-2}
Freshwater ecotoxicity (CTU)	3.22	5.28
Freshwater eutrophication (kg P eq)	5.30×10^{-4}	1.06×10^{-3}
Marine eutrophication (kg N eq)	1.93×10^{-3}	3.70×10^{-3}
Terrestrial eutrophication (mol N eq)	1.75×10^{-2}	2.80×10^{-2}
Carcinogenic effects (ctuh)	1.04×10^{-7}	2.59×10^{-7}
Ionizing radiation (kg U235 eq)	1.41×10^{-1}	2.40×10^{-1}
Non-carcinogenic effects (ctuh)	1.96×10^{-7}	4.51×10^{-7}
Ozone layer depletion (kg CFC-11 eq)	3.92×10^{-7}	3.33×10^{-9}
Photochemical ozone creation (kg NMVOC eq)	5.97×10^{-3}	9.24×10^{-3}
Respiratory inorganics effects (disease inc)	9.02×10^{-8}	2.28×10^{-7}
Dissipated water (m^3 water eq)	2.43	8.37
Fossil use (MJ)	31.9	51.9
Land use (pts)	11.7	28.0
Mineral/metal use (kg Sb eq)	1.79×10^{-5}	1.87×10^{-5}

Table 3. LCIA data for two toothbrush-based programmes.

Impact category	Daily mouth rinse	Weekly mouth rinse
Climate change (kg CO_2 eq)	1.48E+02	2.11E+01
Acidifcation (mol H+ eq)	9.80E-01	1.40E-01
Freshwater ecotoxicity (CTU)	1.13E+02	1.61E+01
Freshwater eutrophication (kg P eq)	1.31E-01	1.87E-02
Marine eutrophication (kg N eq)	2.42E-01	3.46E-02
Terrestrial eutrophication (mol N eq)	1.71	2.44E-01
Carcinogenic effects (ctuh)	2.70E-06	3.86E-07
Ionizing radiation (kg U235 eq)	6.81	9.73E-01
Non-carcinogenic effects (ctuh)	3.54E-05	5.05E-06
Ozone layer depletion (kg CFC-11 eq)	4.63E-05	6.61E-06
Photochemical ozone creation (kg NMVOC eq)	4.11E-01	5.87E-02
Respiratory inorganics effects (disease inc)	4.84E-06	6.92E-07
Dissipated water (m^3 water eq)	7.25E+01	1.04E+01
Fossil use (MJ)	2.42E+03	3.45E+02
Land use (pts)	2.56E+03	3.65E+02
Mineral/metal use (kg Sb eq)	1.32E-03	1.90E-04

Table 4. LCIA data for mouth rinse use by an individual over 5 years.

Impact category	In school	During existing practice appointments	At separate practice appointments
Climate change (kg CO_2 eq)	3.31	1.09	8.12
Acidification (mol H+ eq)	1.14 x 10^{-2}	2.51 x 10^{-3}	3.17 x 10^{-2}
Freshwater ecotoxicity (CTU)	7.04	2.09	18.5
Freshwater eutrophication (kg P eq)	6.70 x 10^{-4}	2.10 x 10^{-4}	1.41 x 10^{-3}
Marine eutrophication (kg N eq)	3.18 x 10^{-3}	1.27 x 10^{-3}	8.35 x 10^{-3}
Terrestrial eutrophication (mol N eq)	2.66 x 10^{-2}	6.94 x 10^{-3}	8.25 x 10^{-2}
Carcinogenic effects (ctuh)	2.99 x 10^{-7}	3.98 x 10^{-8}	3.64 x 10^{-7}
Ionizing radiation (kg U235 eq)	0.140	0.3.92 x 10^{-2}	4.99 x 10^{-1}
Non-carcinogenic effects (ctuh)	3.35 x 10^{-7}	7.33 x 10^{-8}	7.15 x 10^{-7}
Ozone layer depletion (kg CFC-11 eq)	3.12 x 10^{-7}	1.13 x 10^{-7}	1.23 x 10^{-6}
Photochemical ozone creation (kg NMVOC eq)	8.14 x 10^{-3}	1.92 x 10^{-3}	2.72 x 10^{-2}
Respiratory inorganics effects (disease inc)	1.32 x 10^{-7}	2.45 x 10^{-8}	3.27 x 10^{-7}
Dissipated water (m^3 water eq)	1.22	0.717	1.75
Fossil use (MJ)	35.7	7.52	107
Land use (pts)	20.1	5.88	61.5
Mineral/metal use (kg Sb eq)	2.64 x 10^{-5}	4.95 x 10^{-6}	8.92 x 10^{-5}

Table 5. LCIA data for fluoride varnish application.

do not require the same gel consistency as traditional toothpaste.[13] Additionally, toothpaste tablets are lighter than gel toothpaste, which could further reduce their environmental impact. Although no formal life cycle assessment data have been published to confirm this, some evidence suggests that toothpaste tablets are as clinically effective as traditional toothpaste.[15]

School toothbrushing programmes

A study conducted by Ashley *et al* quantified the EI of two toothbrush-based programmes, with results shown in Table 3.[12] The life cycle was based on a single 5-year-old child participating in the programme for a year, and was based on:

- Supervised toothbrushing: a community dental service providing toothbrushes, toothpaste, and a toothbrush bus to a school. The school staff supervise the children brushing their teeth using tap water, once a day, on every school day of the year.
- Provision of toothbrushes and toothpaste: a community dental service delivering toothbrushes and toothpaste in a plastic bag to schools four times a year, which are then distributed to the children. The child then brushes their teeth at home twice a day using tap water.

Both programmes are recommended prevention programmes by Public Health England (PHE) and Childsmile in Scotland.[8,16]

According to Ashley *et al*,[12] supervised toothbrushing has a smaller EI than the provision of toothbrushes and toothpaste. The primary reason for this is the water used for brushing, which contributes significantly to the programme's environmental footprint, accounting for almost half of it. Additionally, the provision of toothbrushes and toothpaste programme involved three times more toothbrushing episodes compared to supervised toothbrushing in schools.

To reduce the EI of these toothbrushing programmes, the authors suggested potential changes, such as using less water when brushing, dry brushing, switching from plastic manual toothbrushes to bamboo or recycled plastic alternatives, and adopting greener methods of staff travel.

These toothbrush-based programmes have a greater impact on population-level prevention than other measures such as water fluoridation. Therefore, it is recommended to use them in a targeted manner, particularly for schools located in deprived or underserved areas, rather than implementing them across the entire population.

Fluoride mouth rinse

Fluoride mouth rinses are recommended for individuals over 8 years of age, who are at high risk of present or future caries.[8] These rinses typically contain 0.05% fluoride solution (daily use) or 0.2% (weekly use). Unlike toothpastes or varnishes, fluoride mouth rinses are not suitable for young children as proper usage requires the ability to rinse and spit without swallowing the solution.

LCA data was calculated for an individual using 10 ml of sodium fluoride mouth rinse for 5 years, comparing the 0.05% daily mouth rinse with 0.2% weekly mouth rinse.[13] Both mouth rinses were assumed to be packaged and transported in the same 500-ml plastic bottle to and from the same location and have the same ingredients (water, glycerine, propylene glycol, sorbitol, peppermint oil, sodium fluoride, sodium saccharine and menthol) with only the sodium fluoride and water amounts varying between the two formulations. The results showed that the daily mouth rinses produced 148 kg of carbon dioxide equivalent, approximately seven times more than the 21.1 kg produced for the weekly mouth rinse (see table). This was because seven times less mouth rinse and plastic bottles are needed for weekly use, compared to daily use. To put this carbon data into context, the weekly mouth rinse has a similar carbon footprint to using a plastic manual toothbrush for the same period of time (25.6 kg).[17]

To summarize, using a fluoride mouth rinse has a more significant EI than using a toothbrush, especially when used daily. This aligns with the Department of Health toolkit, which recommends using a fluoride mouth rinse only when the patient has a high caries risk. It is worth noting that a daily rinse has a higher EI than a weekly rinse, mainly due to the use of more plastic bottles. Clinicians should consider this factor along with the patient's preference. While daily rinses may be more accessible and convenient for patients' oral hygiene habits, their EI should still be taken into account.

Fluoride varnish

Dentists and dental care professionals commonly use fluoride varnishes to deliver fluoride to teeth. These varnishes are not

Impact category	Water fluoridation
Climate change (kg CO_2 eq)	0.443
Acidifcation (mol H+ eq)	5.38×10^{-3}
Freshwater ecotoxicity (CTU)	0.870
Freshwater eutrophication (kg P eq)	9.66×10^{-5}
Marine eutrophication (kg N eq)	9.30×10^{-4}
Terrestrial eutrophication (mol N eq)	9.84×10^{-3}
Carcinogenic effects (ctuh)	1.55×10^{-8}
Ionizing radiation (kg U235 eq)	8.32×10^{-2}
Non-carcinogenic effects (ctuh)	1.47×10^{-7}
Ozone layer depletion (kg CFC-11 eq)	7.24×10^{-8}
Photochemical ozone creation (kg NMVOC eq)	2.89×10^{-3}
Respiratory inorganics effects (disease inc)	4.58×10^{-8}
Dissipated water (m^3 water eq)	0.296
Fossil use (MJ)	8.32
Land use (pts)	4.50
Mineral/metal use (kg Sb eq)	6.62×10^{-6}

Table 6. LCIA results for water fluoridation.

Method of fluoride delivery	5-year carbon footprint (kg CO_2e)	Comments
Toothpaste	10.2 (toothpaste tubes only)	This is based on an individual adult using 6 x 100ml tubes of 1450ppm fluoride toothpaste per year.[25] A majority of the carbon footprint (63%) comes from the ingredient sorbitol. There was no significant change to the CO_2e if the fluoride content is increased to 2800ppm or 5000ppm
	9.75 (supervised toothbrushing in schools)	The two school-based prevention schemes are based on a 5-year-old child participating in this scheme, and includes all the staff travel, toothbrushes, travel, etc
	14.45 (provision of toothbrushes and toothpaste for children in schools)	
Mouth rinse	148	This is based on an individual adult using 10 ml of mouth rinse every day for 5 years. The carbon footprint reduces seven-fold if a weekly mouth rinse is used instead of daily mouth rinse
Fluoride varnish	16.55	This is based on a 5-year-old child receiving two fluoride varnish applications in school. The carbon footprint reduced if the fluoride varnish was instead applied at a pre-existing dental practice visit, and increased if the fluoride varnish was applied at a separate dental practice visit
Water fluoridation	2.2	This is based on fluoridation of the water supply for a single individual for 5 years

Table 7. 'At a glance' summary of the climate change impact of fluoride delivery for caries prevention.

meant for home use, and are applied by a dental professional two to four times a year. They promote a slower release of fluoride than toothpaste and come in different formulations, with Duraphat (5% NaF in a resin/alcohol solvent) and Fluor Protector (0.9% difluorosilane in a polyurethane-based varnish) being the most frequently used.[18] Fluoride varnishes are used as part of preventive dental care at the individual patient level, and in schools as a community intervention.

LCA data in Table 5 compares the EI of fluoride varnish application for an individual 5-year-old child twice in 1 year. It compares the delivery of the varnish in a community-run school programme, and also its delivery in dental practice.[10] According to the data, administering fluoride varnish during an already scheduled dental appointment has the least EI since both patients and staff have already travelled to the dental practice, and equipment and PPE are already in use, with only a small number of additional resources required for applying the varnish. Dental practices committed to sustainability should leverage these opportunities to provide patients with fluoride varnish treatment. It is not advisable to schedule separate appointments for prevention because they have a more significant EI. Public health programmes, such as fluoride varnish application in schools, should also be supported and used in a targeted way, and dental services providing this service can reduce their EI by considering their methods of travel and using reusable instruments where possible.

Silver diamine fluoride

To date, there is no research quantifying the EI of using silver diamine fluoride for caries prevention.

Water fluoridation

Community water fluoridation is the addition of a fluoride compound to a public water supply, with the World Health Organization stating that the 'optimum level' is around 1ppm (part per million).[19] Community water fluoridation was initiated in the USA in 1945, and is currently practised in approximately 25 countries worldwide, including Ireland and some areas of the UK.[20] The rationale behind the role of community water fluoridation is that it benefits both children and adults by effectively preventing caries, regardless of socio-economic status or access to care.[21] A Cochrane review from 2015 concluded

that water fluoridation is effective at reducing caries levels in both deciduous and permanent dentition in children.[22]

A study by Duane *et al* quantified the EI of fluoridation of the public water supply for a 5-year-old child over a 1-year period, based on the Republic of Ireland's method of water fluoridation.[22] Table 6 shows the LCIA results for water fluoridation – like the results for other prevention schemes in Tables 3 and 5, this is representative of the resources needed to provide this prevention for an individual for 1 year.

This study concluded that water fluoridation had the lowest EI of all the community-level caries prevention programmes. The EF of the water fluoridation was compared against the provision of toothbrushes and toothpaste, supervised toothbrushing in schools and the application of fluoride varnish in schools. The greatest overall contributor to the EI of water fluoridation came from the transportation of the diluted HSFA (the fluoridate compound added to water) within Ireland.

Most public health experts consider water fluoridation as one of the top public health measures implemented in the 20th century.[23] Nonetheless, its implementation and use have been met with some controversy. Since its inception, there has been an ongoing debate on whether water fluoridation is detrimental to the environment, with Google searches for 'side effects of fluoride in water' yielding 22.8 million results.[24] Despite this, numerous government organizations have determined that water fluoridation is safe, and its advantages far outweigh any potential risks.[22] The LCA data from this study supports the use of water fluoridation as the community caries prevention scheme with the lowest footprint in all 16 categories of environmental sustainability.

Conclusion

Table 7 provides a summary of the environmental impacts (EIs) associated with different methods of fluoride delivery. Water fluoridation, fluoride toothpaste, varnish, and mouth rinse are all effective delivery methods with published life cycle assessment data. When considering the environmental impact, it is essential to weigh it against clinical effectiveness and cost. It is particularly crucial to assess the environmental impact of population-level interventions that could be widely implemented. Based on the LCAs, water fluoridation had the lowest EI across all 16 impact categories compared to other population-level interventions for caries reduction. By selecting prevention interventions based on clinical, cost and environmental effectiveness, we can reduce CO_2 emissions, pollution, and resource usage while also decreasing healthcare system costs and providing broader economic benefits.[7]

Compliance with Ethical Standards

Conflict of Interest: The authors declare that they have no conflict of interest.
Informed Consent: Informed consent was obtained from all individual participants included in the article.

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